THE STRESSES IN MASONRY DAMS.

THE memoir[1] referred to at the foot of this column embodies the results of further work, mainly experimental, on the design of masonry dams, and is a continuation of the work of Atcherley and Pearson described in an earlier memoir of the same series.[2] In the latter paper the authors discussed the imperfections of the present theory of masonry dams, in which the normal stress on horizontal sections is assumed to be linear, and nowhere tensile. This leads to the well-known condition of stability, that the centre of pressure on horizontal sections must fall within the middle-third, and the linearity of normal stress involves a parabolic distribution of shearing stress. Atcherley and Pearson criticised the action of engineers in ignoring the shear stress distribution, and in merely considering frictional stability as the criterion of safety as regards horizontal sliding. They demonstrated the existence of tension on some vertical sections of existing dams using the common theory, and showed that the mid-third rule was not followed consistently throughout the design.

In the memoir now under review, the authors point out the conditions for a true beam problem, viz.:—(1) the dimensions of cross-section are small compared with the length and with the radius of curvature; (2) true cross-sections, *i.e.* sections perpendicular to the line of centroids, exist. As these conditions are not rigidly fulfilled in a masonry dam, the authors refuse to accept any results based on a simple beam analysis, and proceed to an endeavour to throw experimental light on the current mid-third theory, which they summarise as follows:—

(1) The dam shall not be subjected to tensile stresses.

(2) This involves the line of resistance lying in the middle-third of horizontal sections.

(3) Condition (2) has meaning solely on the assumption that the normal stresses are linear.

(4) Linearity of normal stress involves the distribution of shearing stress being parabolic.

The case of an infinitely long dam, or a dam of finite length abutting against rigid supports, is considered mathematically. It is assumed to be straight, to have a plane face at any batter, and a flank curved in any manner. Regarding it as a homogeneous isotropic material, the laws of elasticity lead to a differential expression of a stress function V, which function has to fit the boundary conditions of the dam, viz.:—(*a*) on face where shear = o; normal stress = water pressure; (*b*) on top and flank, where shear = o; normal stress = o; (*c*) on base, where the shear and normal stresses have their actual values. It is stated that (*c*) is generally ignored, and its existence prevents a mathematical solution being obtained.

The memoir proceeds:—"The engineer using the middle-third rule, and thus assuming the hypothesis of linear normal stress, has *actually* (the italics are ours) assumed the stresses over the base. Consciously or unconsciously he has asserted that the pressure is linear and the shear parabolic." The engineer has perhaps some excuse for his assumption, as a mathematical difficulty cannot stand in the way of building a dam. In many other cases, say that of a large masonry arch, in the light of purely theoretical considerations, the action of the engineer, usually *conscious* we imagine, may savour a little of fools stepping in where angels fear to tread. In saying this, we would in no sense wish to convey the impression that the authors hold engineers responsible for what they regard as the uncertainty in the design of dams. Indeed, they expressly disclaim any such intention, frankly recognising the difficulties of the problem. Their results are put forward as preliminary only to further investigation, which they suggest might possibly be undertaken by some such body as the Institution of Civil Engineers. Their investigation shows that the boundary conditions are best fitted by a triangular dam, but that the conditions cannot hold for rectangular or trapezoidal sections. To quote from the memoir:—"*Purely* mathematical researches suggest no great hope of real advance in what is notwithstanding an urgent practical problem. It does not seem probable that they would provide any but the roughest approximations to the actual conditions." The method by which engineers escape from the horns of the mathematical dilemma is viewed with some misgivings, and the authors seek, in experimental work, a fold in which both engineers and mathematicians may dwell together in harmony

Experimental Work.

The object of the work was to determine the actual straining actions in model dams by direct measurement, and, at the suggestion of the late Sir Benjamin Baker, jelly was adopted as the material of the dams. After much experiment suitable cream-white material made of gelatin, glycerin, and colouring matter was obtained. The size of models was as follows:—base, 45 cm.; height, 35 cm.; breadth, 9 cm. to 10 cm.; substratum, 45 cm.; by 9 cm. or 10 cm. deep. Fig. 1 shows a typical model with lines ruled on the face for the distortion measurements. After much trouble in satisfactorily fixing the models to a rigid wooden base, copper gauze was nailed to the wood and heated. The model was then placed on it, and on cooling was bonded securely to the gauze.

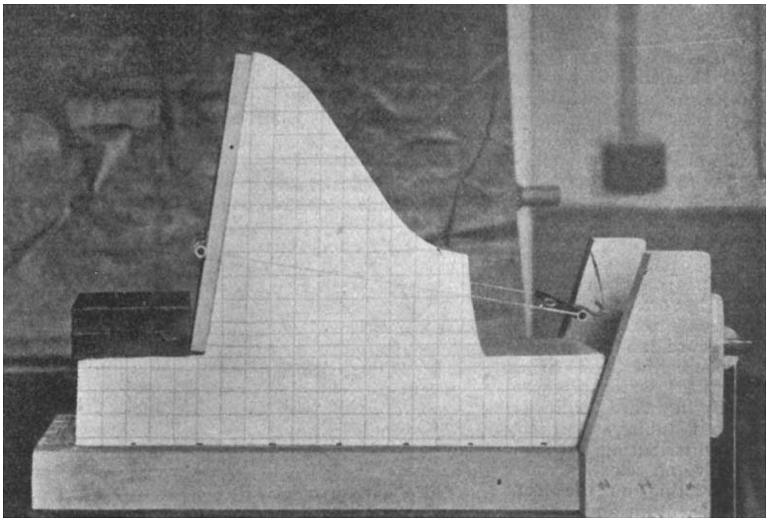

FIG. 1.—Vyrnwy-type dam, moderate water pressure.

Noting the experimental difficulty of attempting to use a dam with rigid, parallel ends, the authors proceed to a mathematical investigation of the stresses in a sheet of elastic material with free sides, *i.e.* a vertical plate with fixed base, no stress on sides, and subjected to a normal stress on part of its edge only. They conclude that with certain limitations there is an identity of stress equations, and that an experimental plate dam without side supports can be used to test the distribution of horizontal shear, by measurement of the distortion of lines ruled on its sides. If the distribution is not parabolic the normal stresses are not linear. The difficulty of measuring the local values of the stretch and squeeze of the jelly prevented any direct estimate of normal stress being obtained, and only the existence of tension in the substratum and the manner of final rupture were noted.

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[1] "An Experimental Study of the Stresses in Masonry Dams." By Karl Pearson, F.R.S., and A. F. Campbell Pollard, assisted by C. W. Wheen and L. F. Richardson. Drapers' Company Research Memoirs. Technical Series v. Price 7*s.*

[2] "On Some Disregarded Points in the Stability of Masonry Dams." By L. W. Atcherley and Karl Pearson, F.R.S. Pp. 44+plates. (London: Dulau and Co., 1907.) Price 3*s.* 6*d.*

Experiments were made on five models:—

(*a*) Water gelatin model, Vyrnwy type, tested to rupture, and illustrating preliminary difficulties.

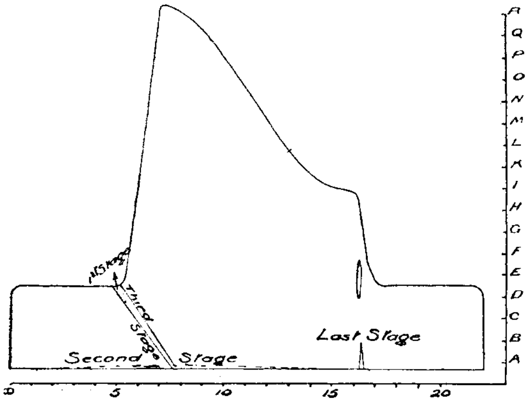
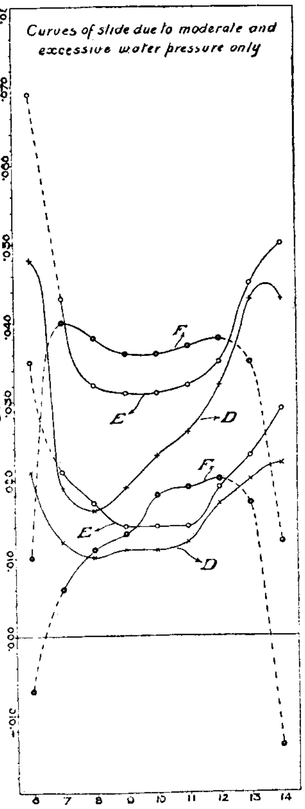


FIG. 2.—Rupture history of a large jelly-dam of the Vyrnwy type.

(*b*) Control dam, Vyrnwy type, very stiff jelly.
(*c*) Dam of Vyrnwy type, moderately stiff jelly.
(*d*) Dam of Assuan type, moderately stiff jelly.
(*e*) Dam of Assuan type, moderately stiff jelly, tested by optical methods.



Curves of slide on the horizontal sections D, E, F.

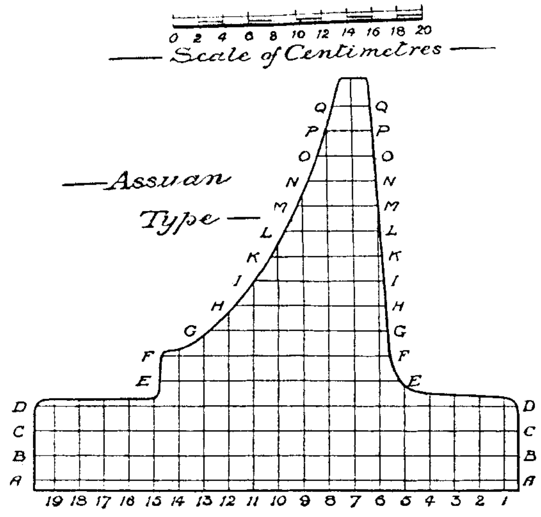
The pressure was applied to the face of the models in three ways:—(1) By a board pressing against the face and loaded normally at the centre of pressure by means of a stirrup and shot bucket. A rubber tube was placed between the board and model to distribute the load so as to imitate water pressure (2) By a board as in (1) without tubing, the jelly itself distributing the load. (3) By an elastic water bag resting on the front of substratum and against the face of the dam, the sides of the bag being rigid and independently supported. The last method gives a true distribution on the face and substratum, and obviates the necessity of piling weights on the latter to maintain equilibrium; but the pressure cannot be varied relatively to the density of the dam as in methods (1) and (2), nor can the dam be tested to rupture. The strains were, in fact, only measurable by delicate optical means.

The Vyrnwy model, tested to rupture, behaved as shown in Fig. 2. The initial cracking gradually extended across the entire front, being followed by the tearing of the jelly from the cement or of the cement itself at the base connection. Then followed the third and last stages, the dam finally toppling over the tail, which separated at the vertical cracks. This experiment indicates weakness in the substratum, and tension across vertical sections at the tail. It may be remarked that the failure occurred at the section of discontinuity of contour, where the stresses in any actual dam become distributed through the surrounding earth in an indeterminate manner, and further that the extent to which the connection of such a model to a rigid base (though good experimentally) imitates the bedding of the substratum of an actual dam is also unknown. The existence of tension on vertical sections is emphasised by the authors.

Distribution of Shear.

This was determined by measuring the angular displacement of lines ruled on the ends of the models. It is admitted that no great exactitude is possible, and the following sources of possible error are indicated:—

(*a*) Inaccuracy of ruling on a jelly face; (*b*) ruling model while resting on its side, giving error especially near the contour; (*c*) distortion due to elastic effect of weight of vertical jelly; (*d*) set due to weight of jelly, or to shrinkage in course of time. The authors think that (*a*) and (*b*), while sensible, are not very large, but that (*d*) is more important, and not easy to determine. If the model is photographed in a vertical position the change of the angles from 90° may not represent the slide due to weight only, since errors (*a*), (*b*), and (*d*) affect the result. Similarly, the combined effect of weight and water pressure cannot be found exactly; but if the model is photographed on the same occasion, with and without water pressure, the errors are largely eliminated, and the change of angle on the two photographs gives the slide due to water pressure alone. The mid-third rule is applied to the cases of reservoir empty and reservoir full. Hence it must apply to the water pressure alone, and the change of angle as measured should give a parabolic curve if the linearity of normal stress holds.



Key figure to the network on the Assuan model.

FIG. 3.

Typical results for the Assuan dam model are shown in Fig. 3 for the sections D, E, and F between verticals 6 and 14. The dotted lines correspond to doubtful measurements near the contour, which, it may be noted, appears to be rather large at section F. There are indications of negative shear near the contours, but the liability to error and uncertainty of measurement must be remembered in any attempt to interpret the curves in this region. There is no resemblance to a parabolic distribution. The curves of shear due to weight, and to weight and pressure combined, shown in the memoir, are extremely wavy in outline, and nothing short of a quartic would in any way represent them between verticals 6 and 14; but bearing in mind the special liability to error in these cases, the curves are not of the same interest as those shown in Fig. 3. Similar results are shown for the Vyrnwy type dam.

As a result of the first set of tests, the authors maintain that, allowing for all irregularity in measurement and material, there is no approach to linearity of normal stress up at least two-thirds, and probably up the whole height of dams of current form. The mid-third rule is, therefore, considered valueless as a stability test, and the success of engineers in building stable dams is attributed more te experience in choice of contours, and in the use of a large factor of safety than to any validity in the method of design. The complexity of the problem and the variations of shear distribution led the authors to make a second series of experiments, using many experimental refinements. The general results were of the same character, and an interesting set of curves is presented showing the actual stresses in the Assuan dam as calculated from the more refined measurements on the model. These curves, like the preceding set, are rather irregular, and it is difficult to believe that they can represent the variations of stress in a body having any approach to homogeneity.

Before concluding the memoir with some attempts at semi-empirical determination of stresses, the following processes are suggested for dealing practically with any proposed design:—

"(1) Form a glycerin-gelatin white pigmented jelly dam of the given contour. Determine the form and fixing of the substratum to represent as closely as may be feasible the local conditions. Rule the surface.

"(2) Apply water pressure and determine by the methods indicated above, using either a direct or optical micro-goniometer, the shear distributions. Ascertain the forms of the horizontal and vertical section shear curves.

"(3) Thence by integration—of course mechanical—find the distribution of normal stress along one or two base sections. From these deduce the stretches and squeezes, and take as definite conditions of stability that the maximum stretch and squeeze shall be less than certain values which may be effectively fixed by experiment."

The authors then say that, with such a test, dams like the Vyrnwy and Assuan are found to be theoretically stable, whereas the mid-third rule gives only an apparent theoretical stability.

We are grateful to the authors for their presentation of the interesting results of such difficult experiments, and hope that their work may bear fruit. Their results must stimulate discussion of a highly important subject; but we imagine that the day is not yet when the civil engineer will proceed to the design of a masonry dam, as the authors suggest, by "forming a glycerin-gelatin white pigmented jelly of the given contour, and determining the form and fixing of the substratum so as to represent as closely as may be feasible the local conditions." Here, it seems to us, there are added to the uncertainties of actual conditions, a set of experimental processes liable to error at many points. He will probably prefer to base a new project on the designs of existing dams, modified as these may be from time to time in the light of new ideas, and perhaps by suggestions coming from work of the character of that under review.

E. BROWN.

THE ETHNOLOGY OF AFRICA.

THE communication by Dr. F. C. Shrubsall—"Notes on some Bushman Crania and Bones from the South African Museum, Cape Town"—issued as part v., vol. v., of "Annals of the South African Museum," in continuation of a paper by the same author in the Journal of the Royal Anthropological Institute for 1897, is an important contribution to the ethnology of that region. Incidentally, it marks a reaction against established methods in anthropometry, which, particularly in the case of mixed races, are now treated with well-merited suspicion. In place of an induction founded upon a single "index" derived from the study of the relative magnitude of one skull dimension in terms per cent. of some other dimension, the present paper is based on no less than eighteen factors, and the figures have been subjected to statistical investigation on the most modern lines.

The inquiry starts from a series, unfortunately limited in numbers, of skulls of the race known as the Strandloopers found in caves along the south-eastern seaboard. These constitute a group more pure than that of the Bushmen, and apparently quite distinct from that of the Hottentots. The up-country Bushmen are intermediate between the Strandloopers and the Hottentots. The latter, again, present dimensions between the up-country Bushmen and the Bantu, and in many characters they approach the Negroes of British Central Africa more closely than the Kafir tribes of the east coast. The Central African Pigmies are by their prognathism clearly removed from the Bushmen, and those of the forest zone seem to be largely mixed with the Negro strain. Thus the purest dwarf race is, or was recently, located on the coast at the extreme south of the continent, the furthest point to which, under pressure, they could retreat.

Eastern and part of south-western Africa are occupied by distinct races of Bantu speech, between whom, in character as well as in position, the Hottentots seem to be intermediate. Quite distinct from these races already mentioned are the Somalis and Gallas, of whose physical character little is known. The Masai further south may be allied to these, but they are quite distinct from the Bantu-speaking Negroes. The West African Bantus, between the Rio del Rey and the Congo, in some respects resemble the eastern tribes of the same stock, in others approximate to the Pigmies.

The race history of South Africa may thus be reconstructed—the first inhabitants were of the Bushman type. Round the great lakes and in the Upper Nile valley the tall Negro tribes were developed, or at least are found in occupation of this region. Pressure from the east drove a large section of these southwards, and these in their turn pressed the Bushmen partly to the extreme southern coast, partly into the forest zone, where they intermingled with their neighbours. Some of the Negroes, again, passed north of the forest tract towards the Atlantic shores, and under pressure of tribes from across the Sahara were in part driven back to the forest, and in part down to the western sea, where in an unsuitable environment their physique deteriorated. Some of these Negroes may have been forced down the Nile valley, taking with them or driving before them any survivors of the northern Bush races, who thus came into contact with Egypt; or, as an alternative, it is not impossible that the range of the Bush peoples may have previously extended much further to the north than is usually supposed.

These conclusions rest, as we have said, on a comparatively small number of skulls. It is to be hoped that a fuller supply of African crania may soon be available by which these interesting speculations may be more adequately tested.

THE PLACE OF THE LABORATORY IN THE TRAINING OF ENGINEERS.[1]

IT is now generally conceded that the advancement and prosperity of an engineering establishment depend upon the number of well-trained employees it possesses, but much difference of opinion exists as to whether the education given in our engineering colleges is of the kind best fitted to produce the type of man who will be of real value to his firm.

As a rule, at the present day, a boy who intends to become an engineer, on leaving school takes up a three or four years' course at an engineering college. On leaving college he will be found to have a fair theoretical knowledge of engineering, to be capable of making a drawing, of testing specimens of materials, of taking indicator cards, and, generally, of carrying on an ordinary engine or boiler trial. As a rule, however, he is incapable of making much practical use of his scientific knowledge, and if compelled to act on his own responsibility in the case of some mechanical problem often fails badly. Many employers thus look coldly on a system of education which produces such poor results, and we have here an explan-

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[1] Based upon a paper read before the Institution of Engineers and Shipbuilders in Scotland, by Prof. A. L. Mellanby.